AUTOMATED DATA COLLECTION FOR PAVEMENT CONDITION INDEX SURVEY

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ABSTRACT

This paper describes the response to the request by the Naval Pavement Center of Expertise and supported by the Tri-Service Pavements Group, to investigate new technology of obtaining field data to increase safety and reduce labor requirements during the data collection for streets, roads, and parking lots. New technology developments have produced a methodology that can quickly inspect roads and streets by using automated inspection equipment such as, but not limited to, a set of video cameras, profiling devices, and laser sensors. This new technology was tried and tested with the Micro PAVER system and compared to the standard process of manual surveys. As part of this evaluation and validation project, evaluation of technology and contractor capabilities was completed. Presently there are three different technologies that are considered acceptable: 35mm analog continuous film, digital camera, and digital line scan imaging. Digital line scan imaging, the newest of the three technologies, was used for this project.

Based on the information obtained during this evaluation, it is concluded that distress measurements taken manually or captured from automated images are consistent, PCI resulting from either manual or automated methodology is consistent, cost associated with both techniques are consistent, and the automated technique is safer and less labor intensive. The automated system has the ability to assess the condition of the pavement and use the resulting data to create and populate a PAVER database. This can be conducted at the same cost or less than manual survey procedures and the surveys become less labor intensive and safe. With the ability of PAVER to accept data from frames, the automated survey is just as feasible to integrate into a roadway pavement management system as is the manual survey.

INTRODUCTION

This demonstration project is in response to the request by the Naval Pavement Center of Expertise and supported by the Tri-Service Pavements Group to investigate new technology of obtaining field data to increase safety and reduce labor requirements during the data collection for streets, roads, and parking lots. This is an effort by the Naval Facilities Engineering Service Center (NFESC) and directly supported by the Army Corps of Engineers' Construction Engineering Research Laboratory (CERL). This demonstration project was sponsored by CNO N46 under the RPM DEMVAL Program of PE 0603725N.

Background

The Navy's Pavement Condition Index (PCI) Guidance [1] provides guidance and direction for implementation of the PCI system for all pavement work including special project validation. The objective is to use the standardized surfaced area maintenance management system to reduce maintenance and repair costs while improving pavement serviceability. The PCI is a numerical indicator based on a scale of 0 to 100 and is a measure of the pavement's integrity and surface operational condition. ASTM D 6433 “Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys” [2] is the standard to follow on performing a survey and to determine the PCI.

Survey field data is presently being obtained manually, which is both labor intensive and relatively unsafe for roads. Data obtained is then used to populate a database in Micro PAVER, an Engineering Management System (EMS) that helps engineers and managers manage the pavement network (roads, streets, and parking lots), determine maintenance and repair (M&R) requirements, and direct resources to maximize return on investment.

For many years the implementation process has been a labor intensive process. New technology developments have produced a methodology that can quickly inspect roads and streets by using automated inspection equipment such as, but not limited to, a set of video cameras, profiling devices, and laser sensors. This new technology needed to be tried and tested with the Micro PAVER system and compared to the standard process of manual surveys.

Scope

This effort investigates new technology to obtain field data that both increases safety and reduce labor requirements during the data collection for streets, roads and parking lots. The primary objectives are to evaluate the ability of the automated PCI survey system to assess the condition of roadway pavement, to use the resulting data to create and populate a Micro PAVER database, and compare the automated system to manual collection, including comparing the PCI resulting from automated versus manual data collection and comparing automated versus manual distress measurements.

This is an effort by NFESC and directly supported by CERL. This effort involves:

(1) Performing a PCI survey and creating a PAVER database.
(2) Observing data collection by the automated system.
(3) Reviewing data interpretation and procedures by the automated survey contractor and CERL when creating and populating the PAVER database.
(4) Evaluating the PCI resulting from automated versus manual data collection and comparison of automated versus manual distress measurements.
(5) Documenting results and preparing draft guidance of appropriate techniques for data collection.

SURVEY TECHNIQUES

Manual

A manual survey is performed following ASTM D 6433 [2]. The pavement is divided into branches that are divided into sections. Each section is divided into sample units. The type and severity of sample distress is assessed by visual inspection of the pavement sample units and the quantity of each distress is measured. Typically, this procedure requires a team of at least two engineers.

A sample unit for unsurfaced and asphalt surfaced roads is defined as an area of 2,500 $\pm$ 1,000 ft^2 (233 $\pm$ 93 m^2). A sample unit for Portland cement concrete (PCC) roads is defined as 20 $\pm$ 8 slabs with joints less than 25 feet (7.6 meters) apart [3]. A determined number of sample units are surveyed by the team, which represents the actual pavement condition of the entire section. Each sample unit is walked upon (or adjacent to depending on traffic control and safety) and the team keeps record sheets for each sample unit surveyed and records the appropriate code for distress type, severity and a measurement of quantity.

Equipment used for PCC surfaced survey include a hand-held odometer for measuring slab size, a ruler and straight edge for measuring faulting and lane/shoulder drop off, and the PCI distress guide for visual reference. Equipment used for asphalt surface survey includes a hand held odometer for measuring length and width of distresses, a ruler and a 10-foot (3 meter) straight edge for measuring the depths of ruts and depressions, and the PCI distress guide.

Automated

An automated PCI survey is a field survey (or data collection) which is automated. The data is collected in the field using cameras, profiling devices, and laser sensors, which are all part of the data collection vehicle. The data is then downloaded into a workstation located at the contractor's facility. Frames are reviewed by engineers (or other qualified personnel), using a computer monitor to visually determine distress type, severity, and quantity. Distresses such as ruts are determined using data generated from a profiling device or laser sensor. When automated survey techniques will be used, it is essential to contract with qualified contractors.

Frames are used for automated data collection in place of samples, as illustrated in Figure 1. Frames consist of one lane wide by approximately 20 feet (6 meter) long. Therefore a 2500 sf sample unit is equivalent to 10 frames (each frame is 12.5 ft * 20 ft = 250 sf). Micro PAVER has an automated procedure that accumulates frames till they reach a sample unit size of 2000 sf for asphalt pavements. If the very last sample unit in the section is less than 1500 sf, it is added to the previous sample unit. This procedure ensures that all sample units will be within the allowable size of 1500 to 3500 sf. Every frame may be inspected or 33 to 50% may be inspected. For example, 50% may be accomplished by inspecting every other frame.

As part of the automated PCI Survey for Pavement Evaluation Demonstration and Evaluation Project, evaluation of technology and contractor capabilities was needed. At the time of this project there were three different technologies utilized by two contractors that were considered for this project. They were 35-mm analog continuous film, digital camera, and digital line scan imaging.

35 mm Analog Continuous Film

CERL had previously contracted with PASCO USA (now CGH Pavement Engineering, Inc.) to perform the initial automated surveys for three Air Force bases using 35 mm analog continuous film technology. CERL indicated that CGH had performed well with an acceptable technology. This technology uses advanced film technology and custom electronics to obtain high-resolution, 35 mm film images of the pavement surface. The pavement surface images are collected using continuous strip photography. The images cover a width of 16 feet (4.9 meters) and cracks as fine as 0.04 inch (1mm) in width can be recorded at speeds up to 60 mph (100 km/hr).

This system consists of a boom-mounted, 35 mm slit camera, electronic controller, and custom illumination system. The data collection vehicle is shown in Figure 2. The electronic controller synchronizes the film speed to the speed of the vehicle so that there is no loss in resolution with changes in vehicle speed. The illumination system consists of an array of halogen lights mounted in a custom bumper. This system allows control of the angle and degree of illumination on the pavement surface for maximum resolution. The images collected are at a 1:200 scale. These images are analyzed to determine the types, severity, and extent of pavement distress at the workstations located at CGH. A workstation is shown in Figure 3.

This system also uses a pulse camera, which photographs the transverse profile of the roadway at selected intervals to determine rut depth and shoulder drop-off. The pulse camera is synchronized with a hairline strobe projector mounted on the rear bumper and maintains a precision of $\pm$ 2 mm and is synchronized to the actual vehicle speed.

Digital Camera

CERL had previously contracted with Quality Engineering Solutions, Inc. (QES) to survey three additional Air Force bases using digital camera technology (equipment owned and located at the University of Arkansas). During this project, representatives of NFESC and CERL visited QES to determine if the contractor's capabilities and the technology were acceptable. QES was found to be an acceptable contractor with acceptable technology requiring some modification.

This technology uses a digital camera with strobe lighting. The imaging system collects full pavement width of 14 feet (4.3 meters) at the resolution of 1,300 x 1,024 pixel images in a continuous fashion. Data collection ranges from 1 to 60 miles per hour (1 to 100 kilometers per hour) and all images are stored in an onboard computer system. Images are generally collected at night using strobe lighting. Camera adjustments are made either manually or automatically to ensure that high quality images are collected. Images are then stitched together (computer software package) to form a continuous image of the pavement surface. Image location is closely controlled through a highly accurate distance measuring instrument (DMI) and the use of global positioning. The data collection vehicle is shown in Figure 4.

Data processing is completed in the office using the continuous image viewer as illustrated in Figure 5. The pavement images can be scrolled forward or backward at varying speeds. A scaled grid is laid over the image to assist in quantifying the distresses. The distress ratings are then recorded in an Access database. Pavement ride and rutting data are collected using three to five laser devices, with standard processing algorithms. Roughness can be provided in International Roughness Index (IRI), or other format.

Digital Line Scan Imaging

This technology is the most recent development for automated surveys and was employed by CGH Engineering. Although this technology had not been proven, CGH Engineering, incorporating digital line scan imaging, was the successful contractor when this project went out for bid. During this project, a representative from NFESC visited CGH to determine if the contractor's capabilities using this technology, along with the technology itself were acceptable. It was determined that CGH was acceptable and the technology was proven to be acceptable during this project.

The digital system uses state-of-the-art digital imaging technology to collect continuous, high-resolution images of the pavement surface. The digital imaging system consists of a 2,000-pixel digital line scan camera, illumination system, and computerized controller. The line scan camera is set to cover a width of 14.5 feet (4.4 meters). Data collection speed ranges from 1 to 60 miles per hour (1 to 100 kilometers per hour) and all images are stored in an onboard computer system. Images are generally collected at night using an illumination system, which consists of an array of halogen lights mounted in a custom bumper. The data collection vehicle is shown in Figure 6.

Data processing is completed in the office. Images are analyzed to determine the types, severity, and extent of pavement distress at the workstations located at CGH. A workstation is shown in Figure 7. This system also uses a pulse camera, which photographs the transverse profile of the roadway at selected intervals to determine rut depth and shoulder drop-off. The pulse camera is synchronized with a hairline strobe projector mounted on the rear bumper and maintains a precision of $\pm$ 2 mm and is synchronized to the actual vehicle speed.

Manual and Automated Costs

Manual PCI surveys on roads were completed at 12 bases (primarily housing) during the year 2000 by the NAVFACENGCOM Southwest Division pavement team. Actual locations, amount of area surveyed, and cost per yd^2 is shown in Table 1. In general, cost rose from approximately \$0.11/yd^2 for 100,000 square yards surveyed to approximately \$0.70/yd^2 for 25,000 square yards surveyed (\$0.13/m^2 for 84,000 square yards to \$0.84/m^2 for 21,000 square meters). Costs remained constant at approximately \$0.10/yd^2 (\$0.13/m^2) with surveyed areas greater than 100,000 yd^2 (84,000 m^2). Based on this curve (illustrated in Figure 8), for the area surveyed at NSA Mid-South of approximately 405,000 yd^2 (~340,000 m^2), the manual survey cost would be estimated at \$0.10/yd^2.

The 405,000 yd^2 (340,000 m^2) was completed by automated survey. The cost of developing M&R scenarios, initial meetings, completing the survey, populating the database, performing GIS linkage, and completing the report was \$35,000 or \$0.09/yd^2 (\$0.12/m^2). This cost is similar to the approximately \$0.10/yd^2 (\$0.13/m^2) that CERL has estimated on previous projects. Therefore, at the present time, the cost of completing a PCI survey by incorporating manual surveys or automated surveys are approximately the same for surveyed areas greater than 100,000 square yards (84,000 m^2).

FIELD PREPARATION

Preliminary Inventory

Prior to performing pavement condition measurements by any technique, the pavement network must be defined so as to divide the network into manageable sections for both network and project level management. The network is divided into branches (i.e., a specific road would be a specific branch) and branches are divided into sections using factors such as pavement type, traffic, construction history, structure, and so on. This is generally a one-time effort, as long as it is completed properly and with the "best" information available. This effort, or initial data collection, for each pavement section can be very time consuming, but must be completed.

This task must be completed with input from personnel that are knowledgeable regarding the history of the pavement and future planning for the roads and parking lots. In addition, input from the parties that are responsible for the network pavement management for both network and project level management is essential. This network definition process will take several days with the activities representatives to complete. Guidelines to establish a pavement network can be found in Reference 3.

Survey by Sample/Frame

Several sections were marked so comparisons could be made at the exact locations by both manual and automated techniques. These sections were marked so they would be compatible with the automated data collection procedure. The pavements were marked at 0', 20' and 40'; 120', 140' and 160'; 240', 260' and 280' (0, 6 and 12 meters; 37, 43 and 49 meters; 73, 79 and 85 meters); and so on, allowing frames to be taken from 0' to 20' and 20' to 40'; 120' to 140' and 140' to 160' (0 to 6 meters and 6 to 12 meters; 37 to 43 meters and 43 to 49 meters); and so on.

Data collected in these sections were used to compare distresses measured by each technique and determine PCI by use of "frames" using both techniques. The manual PCI was conducted by measuring distresses in each of the marked "frames" and combining those to make one sample for each 2,000 to 2,500 square feet (186 to 233 square meters) of area surveyed.

Survey by Section

Several additional sections were selected to perform a complete manual survey using ASTM standards as previously described. These sections were surveyed manually using samples and were not disclosed to the contractor as to which were conducted manually. In addition to these sections, all 144 sections were driven/walked upon to develop an overall review to compare automated results. This would be called a "windshield survey" where distresses are not recorded and measurements are not taken, hence a PCI is not determined. This quick review of all the pavements, based on engineering judgement, was used to get an overall "impression" of pavement condition. All 144 sections were surveyed by the automated technique as previously described and a complete PCI survey report, incorporating all of the automated data, was submitted to Naval Support Activity Mid-South [4].

RESULTS

Automated Versus Manual Pavement Distress Measurements

Pavement sections that were marked, so comparison of automated versus manual distress measurements could be completed, were WASP 04, SINGLETON 06, and TICONDEROGA 01. The following data represents these sections, which include the stationing marked on the pavement and the distress type, severity, and quantity for both manual and automated techniques. Results indicate that in general, distress type and quantity are consistent between techniques and the severity is somewhat inconsistent. However, severity appears to be typically lower by the automated system. Consistent distress type and quantity between techniques indicate both field procedures produce similar results. The inconsistency of the severity indicates similar concerns that are present during any survey, which is interpretation of the level of severity from person to person. Reviewing the pavement at a workstation where distress can be magnified may produce more accurate measurements and better consistency from person to person. Distress types and severity are described in Reference [5].

		Manual				Automated			
	Station	Distress	Severity	Quantity		Distress	Severity	Quantity	
WASP 04	0 – 20	10	L	21’	6.4 m	10	L	21’	6.4 m
	20 – 40	10	L	3’	0.9 m	10	L	3’	0.9 m
	120 – 140	10	L	8’	2.4 m	10	L	11’	3.4 m
	140 – 160	10	L	7’	2.1 m	10	L	6.5’	2 m
	240 – 260	10	L	11’	3.4 m	10	L	13’	4 m
	260 – 280	-	-	None		-	-	None	
	360 – 380	10	L	3’	0.9 m	10	L	1.5’	0.5 m
	380 – 400	10	L	11’	3.4 m	10	L	14’	4.3 m
SINGLETON 06	0 – 20	3	M	250 ft^2	23 m^2	3	L	250 ft^2	23m^2
	20 – 40	3	M	250 ft^2	23 m^2	3	L	250 ft^2	23m^2
		19	L	25 ft^2	2.3 m^2				
	120 – 140	3	L	250 ft^2	23 m^2	3	L	250 ft^2	23 m^2
		7	M	14’	4.3 m	7	M	14’	4.3 m
		19	L	10 ft^2	1 m^2				
	140 – 160	3	M	250 ft^2	23 m^2	3	L	185 ft^2	17 m^2
							M	65 ft^2	6 m^2
	240 – 260	3	L	250 ft^2	23 m^2	3	L	250 ft^2	23 m^2
	260 – 280	3	L	250 ft^2	23 m^2	3	L	250 ft^2	23 m^2
	360 – 380	3	M	250 ft^2	23 m^2	3	L	250 ft^2	23 m^2
	380 – 400	3	M	250 ft^2	23 m^2	3	L	250 ft^2	23 m^2
	480 – 500	10	L	40’	12 m	10	L	40’	12 m
						7	L	3’	1 m
	500 – 520	10	L	40’	12 m	10	L	39’	12 m
TICONDEROGA 01	0 – 20	3	M	210 ft^2	19.5	3	L	145 ft^2	13.5 m^2
						1	L	15 ft^2	1.4 m^2
						10	L	53’	16.2 m
	20 – 40	3	M	210 ft^2	19.5	3	L	210 ft^2	19.5 m^2
	120 – 140	3	H	210 ft^2	19.5	3	M	120 ft^2	11.1 m^2
							H	90 ft^2	8.4 m^2
						1	M	15 ft^2	1.4 m^2
	140 – 160	3	M/H	100/100 ft^2	9.3/9.3m	3	M	110 ft^2	10.2 m^2
		11	M	10 ft^2	0.9 m	1	M	100 ft^2	9.3 m^2
	240 – 260	10	L/M	2/10.5’	0.6/3.2m	10	M	30’	9.2 m
		7	M	10’	3 m				
	260 – 280	10	M	10.5’	3.2 m	10	M	20’	6.1 m
		7	M	10’	3 m				
		3	L	60’	18.3 m				

Automated Versus Manual PCI Determination

Pavement sections that were marked, so comparison of automated versus manual PCI could be completed, were WASP 04, SINGLETON 06, TICONDEROGA 01, and TARAWA 01, 02, and 03. These sections were marked so they would be compatible with the automated data collection procedure. Therefore, manual PCI was conducted by measuring distresses in each of the marked “frames” and combining those to produce 2,000 to 2,500 square foot (186 to 233 square meters) samples. The following PCI values indicate both survey techniques, using the same pavement areas to determine PCI, result in similar values. The results on Singleton 06 indicate the inconsistency of severity, as discussed above, and when the severity is consistent, the PCI is consistent.

	Manual PCI	Automated PCI
TARAWA 01	83	81
TARAWA 02	38	39
TARAWA 03	67	72
WASP 04	84	85
SINGLETON 06	59	79 (61[1])
TICONDEROGA 01	40 (38[2])	35

Note: (1) PCI if severity of distresses were M as they were for the manual survey.
(2) PCI when and additional sample unit was added.

PCI of Sections

The additional sections selected to perform a complete manual survey using typical manual procedures were INTREPID 01, 02, 03; ORISKANY 01, 02, 03; KEARSARGE 01, 02, 03; and CLUB DRIVE 01. These sections were surveyed manually using samples and were not disclosed to the contractor as to which were conducted manually. The following PCI values indicate both survey techniques result in similar values. Typically, results within 5 points of one another, using the same technique, would be considered satisfactory.

	Manual PCI	Automated PCI	Difference
INTREPID 01	87	85	-2
INTREPID 02	64	60	-4
INTREPID 03	30	34	+4
ORISKANY 01	33	35	+2
ORISKANY 02	89	86	-3
ORISKANY 03	94	89	-5
KEARSARGE 01	27	86	*
KEARSARGE 02	53	52	-1
KEARSARGE 03	55	60	+5
CLUB DRIVE 01	16	13	-3

Note: * Incorrect part of section used. KEARSARGE 01 is part of a parking area and based on the results, it is apparent that the two procedures followed a different centerline. Based on the existing conditions, shifting of the centerline along this section would in fact change the PCI significantly. Therefore, when this occurs, closer attention needs to be given to where the road is actually centered.

In addition to these sections, all 144 sections were driven/walked on (“windshield survey”) to develop an overall review to compare automated results. Distresses were not recorded and measurements not taken, hence a PCI was not determined. During this “survey” 61 pavement sections were highlighted on a base map, which based on engineering judgment, were expected to be very good to excellent. Results from the automated PCI survey indicated 68 pavement sections to be very good to excellent (PCI = 71-100); however, 58 of these sections were 80 to 100. All 58 sections were included in the 61 sections estimated to be very good to excellent.

CONCLUSIONS AND RECOMMENDATIONS

Field data obtained during a PCI survey is presently being performed manually, which is both labor intensive and has personnel safety concerns. New technology developments have produced a methodology that can quickly inspect roads and streets by using automated inspection equipment such as, but not limited to, a set of video cameras, profiling devices, and laser sensors. Following the survey, distresses are visually identified and measured from captured images. This new technology was tried and tested with the Micro PAVER system and compared to the standard process of manual surveys.

As part of the Automated PCI Survey for Pavement Evaluation Demonstration and Evaluation Project, evaluation of technology and contractor capabilities was completed. Presently there are three different technologies that are considered acceptable. They are 35mm analog continuous film, digital camera, and digital line scan imaging. Digital line scan imaging, the newest of the three technologies, was used for this project.

Based on the information obtained during this evaluation, the following conclusions can be made:

- Comparison of automated versus manual distress measurements indicates both techniques result in similar measurements.
- Comparison of automated versus manual PCI indicated both techniques result in similar PCI when compared on the same pavement area.
- Comparison of PCI of sections, using automated survey methodology and manual survey methodology, indicated PCI is similar when using either methodology.
- Populating the PAVER database was successful using MicroPAVER 5.0 (Beta Version); executing the MicroPAVER 4.2 with the database populated in the "frame" format was also successful.
- Actual time to survey 405,000 yd^2 (340,000 m^2) included half of 1 night and morning of 1 day. Therefore, there was only 4 to 6 hours that traffic was slightly impacted with virtually no safety-related issues for personnel.
- Cost to perform automated survey of the 405,000 yd^2 (340,000 m^2) was similar to manual surveys.

The automated system has the ability to assess the condition of the pavement and use the resulting data to create and populate a PAVER database. This can be conducted at the same cost or less than manual survey procedures and the surveys become safer and less labor intensive. With the ability of PAVER to accept data from frames, the automated survey is just as feasible to integrate into a roadway pavement management system as is the manual survey.

Therefore, it is recommended to consider using automated survey techniques to reduce labor needs and increase safety of any personnel (in-house or contractor) that may conduct the surveys.

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TABLE 1 Cost of Manual PCI Surveys

Housing and Other Pavement Condition Surveys				
Location	**Miles**	**Cost**	**Area (ft^2)**	**$ per yd^2**
China Lake	4.37	$9,234	744,262.00	$0.11
Concord	2.85	$11,400	395,778.00	$0.26
El Centro	1.68	$6,150	244,492.00	$0.23
Everett	1.75	$9,000	142,682.00	$0.57
Fallon	3.17	$9,511	534,474.00	$0.16
Jackson Park	5.13	$11,233	651,336.00	$0.16
Lemoore	13.2	$19,990	2,004,745.00	$0.09
Monterey	5.87	$14,375	790,737.00	$0.16
Point Mugu	6.7	$12,201	1,214,196.00	$0.09
Port Hueneme	4.28	$10,156	672,917.00	$0.14
Seal Beach	0.95	$5,500	162,834.00	$0.30
Whidbey Island	15.68	$16,250	208,701.00	$0.70

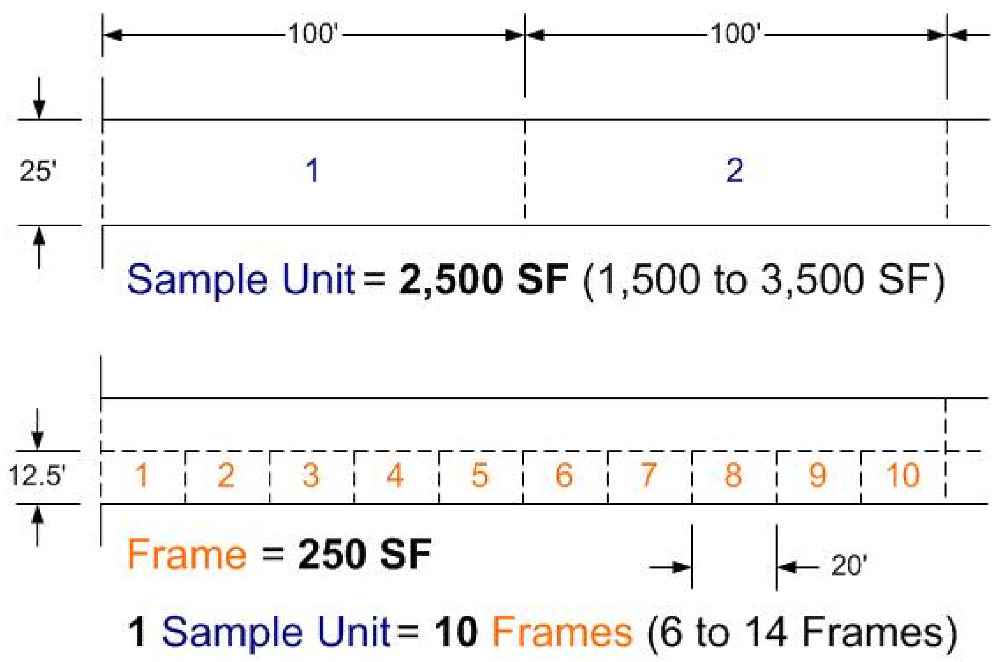

FIGURE 1 Frames are used for automated data collection in place of samples.

FIGURE 2 Data collection vehicle for 35 mm analog continuous film technology.

FIGURE 3 Workstation for 35 mm analog continuous film technology.

FIGURE 4 Data collection vehicle for digital camera technology

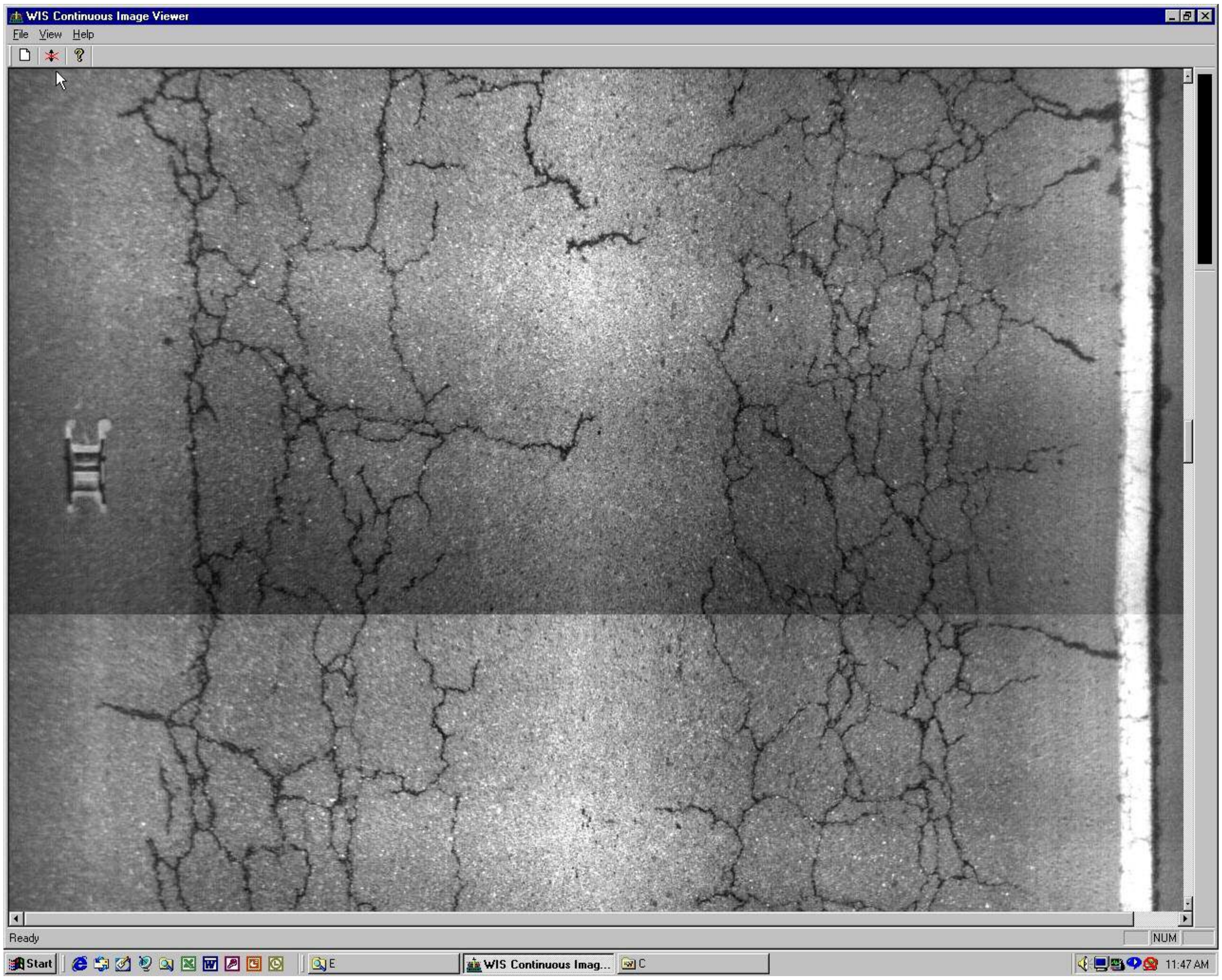

FIGURE 5 Continuous image viewer for digital camera technology.

FIGURE 6 Data collection vehicle for digital line scan imaging technology.

FIGURE 7 Workstation for digital line scan imaging technology.

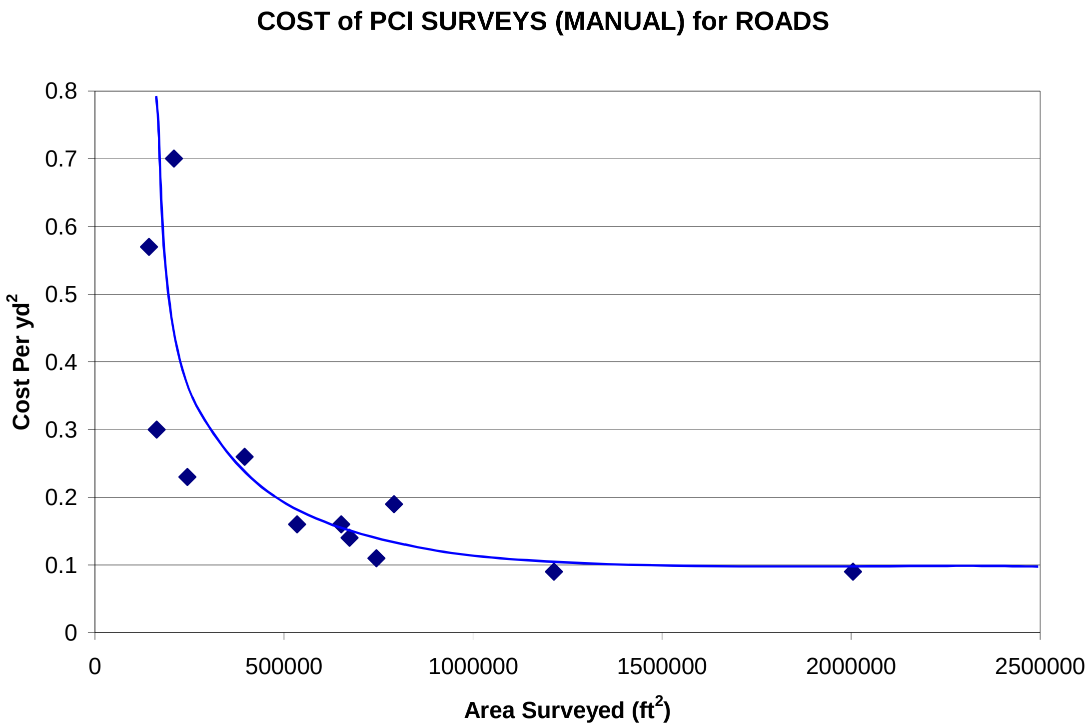

FIGURE 8 Cost of PCI surveys (manual) for roads.